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FINAL REPORT

SPACE SHUTTLE MAIN ENGINE STRUCTURAL ANALYSIS AND DATA REDUCTION/EVALUATION

VOLUME 5: MAIN INJECTOR LOX INLET ANALYSIS

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FOREWORD

This volume of the Final Report summarizes the analysis performed on the Main Injector LOX Inlet Assembly located on the Space Shuttle Main Engine. An ANSYS finite element model of the inlet assembly was built and executed by Chana D. Johnson and Rebeca S. Violett in the Structures & Mechanics Section of the Lockheed-Huntsville Engineering Center under Contract NAS8-37282. Static stress analysis was performed by Rebeca S. Violett.

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1. INTRODUCTION AND OVERVIEW

The main injector LOX inlet assembly directs oxidizer flow from the main oxidizer valve to the main chamber oxidizer dome and main chamber augmented spark igniter. Figure 1 shows the location of the inlet with respect to the main injector.

A static stress analysis was performed on the inlet assembly to evaluate the stress levels on the inlet components. Those areas of primary concern were around the welds. The analysis load case consisted of a constant internal pressure and a pipe load due to the pressure in the LOX line.

A three-dimensional finite element model was generated using ANSYS to perform the stress analysis. The model was generated on Lockheed's VAX 11/785 computer and executed on the EADS system.

The remaining sections of this report consist of descriptions of the model, boundary conditions and external loads, material properties, structural analysis and results, a summary, and recommendations.

2. MODEL DESCRIPTION

A finite element model of the left side of the Main Injector LOX Inlet Assembly was generated using ANSYS. The right side of the inlet is identical to the left side except for the end cap. Figure 2 is a hidden line mesh plot of the ANSYS finite element model. The model consists of six components: the manifold shell, end cap and base, the inlet tee and vane, the elbow, and the flange. Figure 3 shows cutaway views of all these components. Table 1 lists the model components, provides a count of the number of nodes and elements, and identifies the type of elements used for each component. Note that this model uses isoparametric solid elements (STIF45) and quadrilateral and triangular shell elements (STIF63).

Table 1 NODE AND ELEMENT BREAKDOWN FOR MAIN INJECTOR LOX INLET COMPONENTS

NODES & ELEMENTS FOR MAIN INJECTOR LOX INLET			
COMPONENT	**DRAWING NUMBER**	**NODES**	**ELEMENTS**
Manifold Shell	RS009235-001	356	375 Shell
Manifold End Cap	RS009154-005	138	239 Shell
Inlet Tee and Vane	RS009234-015	452	786 Shell
Elbow	RS009147-017	187	160 Shell
Manifold Base	RS009124-023	7375	5975 Solid
Flange	RS009425-005	85	32 Shell 16 Solid
TOTALS		8459	7583

Specific model information is provided in Table 2. The element type number information is useful for selecting a range of elements by type. Each component has a different type number; therefore all the elements in a component may be selected using the ANSYS ERSEL, TYPE command. For example, to select all the manifold shell elements, the following command would be used:

ERSEL,TYPE,6,7.

Also listed in Table 2 are the coordinate systems used to generate each component. Figure 4 shows the location of coordinate systems 0, 11, and 22 with respect to the center line of the main injector. Figure 5 is a cross sectional view of the tee showing the location of coordinate system 12. Figure 6 is a typical cross-sectional view of the base, at STA 0, showing the location of coordinate system 28. A Cartesian coordinate system, such as 28, was defined for each of the 13 stations of the base. Defining a coordinate system for each station simplified the model generation. Figure 7 is an element plot of the flange showing the location of coordinate system 15.

Table 2 INLET MODEL DATA

COMPONENT	TYPE NO.	ELEM. TYPE	ELEM. RANGE	NO. OF ELEM.	THICKNESS	COORD. SYS.
Tee-Elbow Interface	1	63	566-604	39	0.24	
Tee-Shell Interface	2	63	502-565	64	0.157	
Tee-Shell Interface	2	63	916-946	31	0.157	
Vane	3	63	605-755	151	0.22	11 and 12
Elbow	4	63	756-787	32	0.24	12
Elbow	5	63	788-915	128	0.119	11
Shell	6	63	997-1008	12	0.157	11
Shell	6	63	1011-1012	2	0.157	11
Shell	6	63	1027-1040	14	0.157	11
Shell	6	63	1043-1044	2	0.157	11
Shell	6	63	1047-1065	19	0.157	11
Shell	6	63	1068-1069	2	0.157	11
Shell	6	63	1072-1085	14	0.157	11
Shell	6	63	1100-1101	2	0.157	11
Shell	6	63	1104-1110	7	0.157	11
Shell	6	63	7462-7627	166	0.157	11
Shell	7	63	1113-1247	135	0.093	11
Cap	8	63	6158-6268	111	0.157	22
Cap	9	63	6269-6396	128	0.093	22
Manifold Base	10	45	1248-6157	4910	-	28 thru 40
Manifold Base	10	45	6397-7461	1065	-	28 thru 40
Tee	11	63	1-501	501	0.119	11 and 12
Flange	15	63	947-962	16	0.24	15
Flange	15	63	963-978	16	1	15
Flange	16	45	979-994	16	-	15

Plate elements on the manifold shell and inlet tee were connected to the solid elements on the base by multiple point constraints. Figure 8 shows how typical plate/solid element interfaces were implemented in the model. The coincident plate/solid interface nodes were merged, and a partial set of constraint equations was generated for the solid element offset nodes at the interface. Generating a partial set of rigid region equations is useful for transmitting the bending moment between the solid and plate elements.

The IBM and Cray runstreams which generated and executed the main injector LOX inlet model are included in Appendix A.

3. BOUNDARY CONDITIONS AND EXTERNAL LOADS

The boundary conditions for the main injector LOX inlet model consisted of constraints on the plane of symmetry and on the manifold base/LOX dome interface. Symmetry constraints were applied on the plane of symmetry (θ = 213) as follows: the local Y translational and X and Z rotational displacements in coordinate systems 11 and 15 were set to zero; the local Z translational and X and Y rotational displacements in coordinate system 12 were set to zero. On the manifold base/LOX dome interface, all translations were fixed at the locations where the base is welded to the LOX dome.

The loading on the inlet model was a nominal load case consisting of pressure loads and a pipe load. A nominal pressure (4320 psi) was applied to all interior surfaces of the manifold shell, cap, inlet tee, elbow, and flange, and to all manifold base elements which are extensions of the shell. No pressure load was applied to the vane. The pipe load, due to the pressure in the LOX line, was applied as an axial load (650 lbf on each node) at the flange/LOX line interface. One half of this value (325 lbf) was applied on the flange nodes which lie on the plane of symmetry.

The thermal environment for the inlet is -265 °F, which is the temperature in the injector dome. This temperature was applied as a uniform temperature to all nodes. The nodal temperatures are used for evaluation of the material properties of Inconel 718 at -265 °F, not for thermal loads.

4. MATERIAL PROPERTIES

The material used for the main injector LOX inlet is Inconel 718. All material property information was obtained from the Rocketdyne Materials Properties Manual.

Inconel 718 material property data were curve fitted to cubic polynomials for ANSYS input over the temperature range of 0 to 2000 °R. Extrapolation beyond 2000 °R is questionable. However, the expected temperature range for this analysis is from 100 to 1500 °R, well within the selected curve fit limits. Young's modulus, Poisson's ratio, and the coefficient of thermal expansion for Inconel 718 as functions of absolute temperature are presented in Figures 9, 10, and 11, respectively.

Material property data for the weld regions (Refs. 1 through 3) were not submitted by MSFC until recently; therefore that information was not used in this analysis.

5. STRUCTURAL ANALYSIS/RESULTS

The ANSYS finite element model was used to determine the stress distribution on the main injector inlet under a nominal load case. Margins of safety were not computed because the maximum load conditions were not analyzed.

Principal stress contour plots of the inlet components are shown in Figures 12 through 17. Table 3 lists the ANSYS calculated maximum stress in each component and at the weld areas. These values were determined from Figures 12 through 17.

Table 3 INLET STRESSES

COMPONENT OR WELD	WELD NUMBER	MAXIMUM STRESS, KSI
Manifold Shell	-	89.4
Manifold Cap	-	39.7
Base	-	157.1
Tee and Vane	-	163.0
Elbow	-	107.9
Flange	-	48.4
Shell seam weld	1 *	54.1
Shell/Tee weld	15 **	47.0
Shell/Base weld	7, 53 **	47.0
Shell/Cap weld	12 **	51.5
Cap/base weld	44 **	55.5
Tee/Base weld	16, 17 **	73.2
Tee/Elbow weld	13 **	96.0
Elbow/Flange weld	17 ***	48.4

* See Reference 1.

** See Reference 2.

*** See Reference 3.

The highest stressed elements are in the region where the two toroidal shapes intersect to form the inlet tee. The wall thickness in this region of the tee varies from 0.119 to 0.24 inch but it was modeled with a nominal thickness of 0.119 inch. The inlet tee was modeled in this manner because the drawings of this component were not detailed enough to model the varying wall thickness.

The stresses in the manifold shell are highest in the vicinity of the shell/tee interface. For the manifold base, the largest stresses are in the base/tee interface. The highest stressed area for the elbow is in the inside bend. The manifold cap and the flange are not overstressed. The highest stress in the weld regions is located at the tee/elbow interface.

6. SUMMARY

Under a nominal load case, the inlet exhibits highest stresses at the tee. Careful study of this region shows that a conservative element thickness was used. Table 4 is a summary of the results for the nominal load case.

Table 4 INLET STRESS ANALYSIS - SUMMARY OF RESULTS

COMPONENT	MAXIMUM STRESS, KSI
Manifold Shell	89.4
Manifold Cap	55.5
Base	157.1
Tee and Vane	163.0
Elbow	107.9
Flange	48.4

An accurate stress analysis of the main injector LOX inlet assembly requires a knowledge of the maximum load case, the material data for the proper heat-treatment conditions, and additional detailed drawings for the inlet tee.

7. RECOMMENDATIONS

In order to properly perform a detailed stress analysis on the Main Injector LOX Inlet Assembly, several pieces of information are needed:

1. Additional drawings for the inlet tee showing more detail on the varying wall thickness.
2. Loads for maximum load case.
3. Additional material data for the proper heat-treatment conditions.

Once the above information is obtained, the following tasks could be performed to expand this analysis:

1. Generate an accurate model of the inlet tee.
2. Analyze maximum load case.
3. Write margins of safety.
4. Identify critical stress points.

8. REFERENCES

1. Weld Assessment Program, Document No. RSS-8756, Assembly of Shell, Inlet-Oxidizer.

2. Weld Assessment Program, Document No. RSS-8756, Assembly of Body-Injector.

3. Weld Assessment Program, Document No. RSS-8756, Assembly of Powerhead-Rocket Engine.

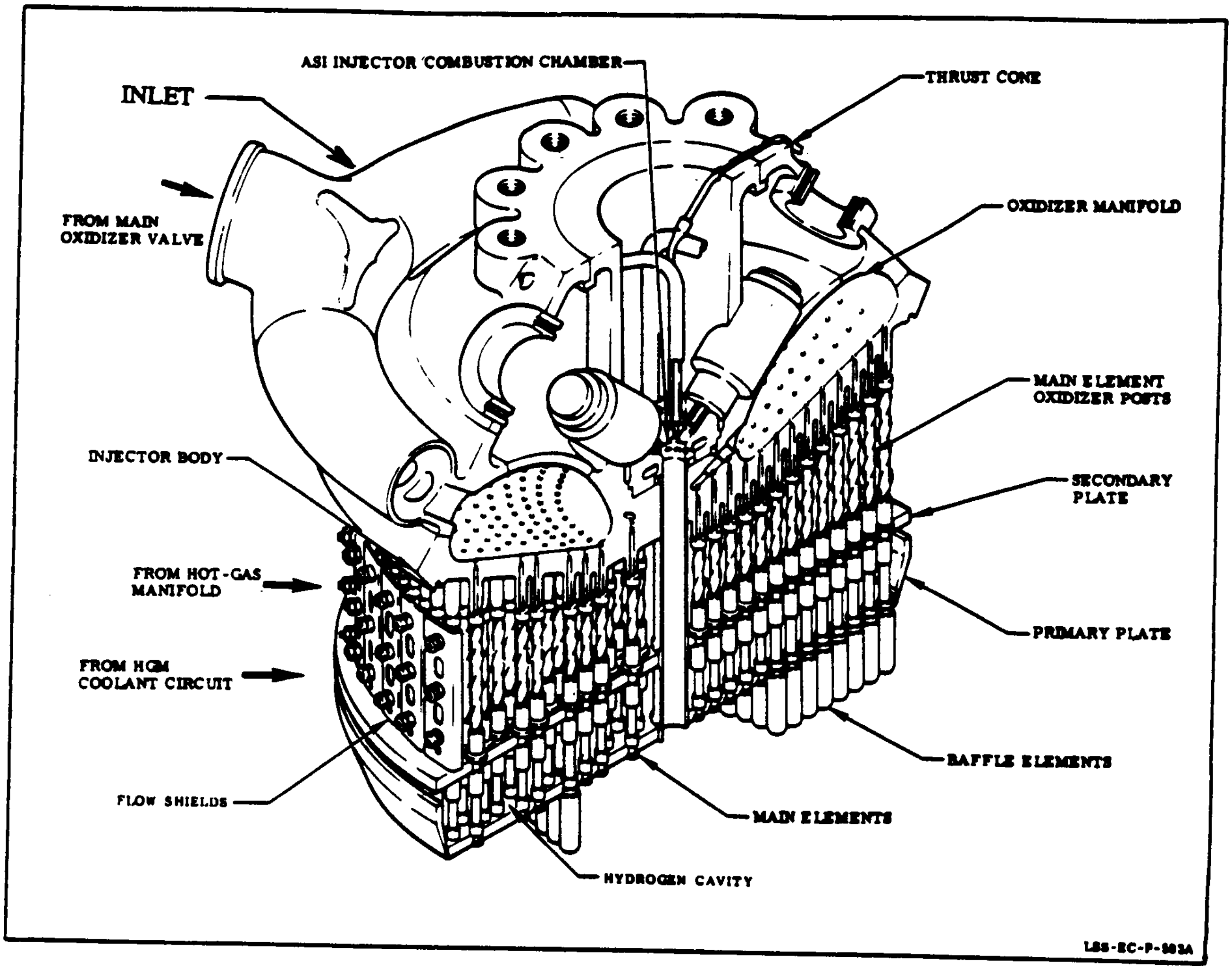

Figure 1 Main Injector

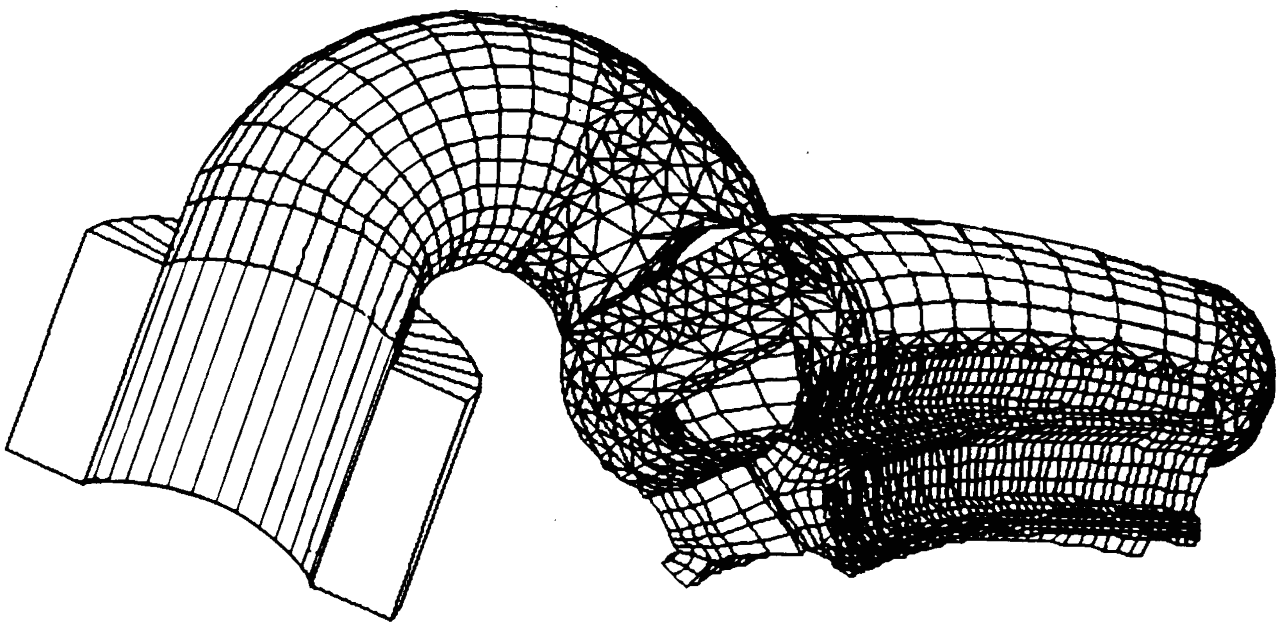

Figure 2 Main Injector LOX Inlet Model

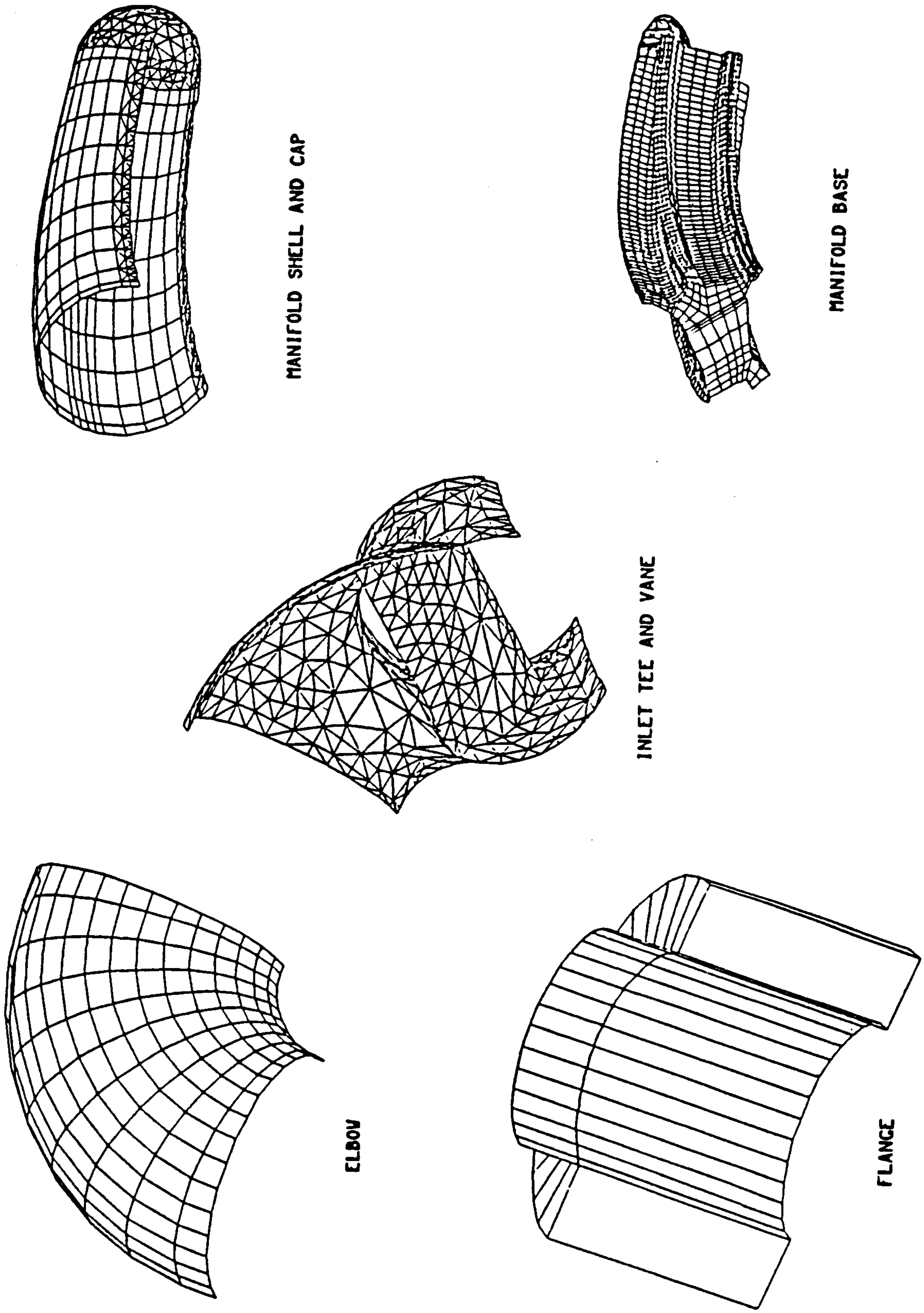

Figure 3 Cutaway Views of Inlet Components

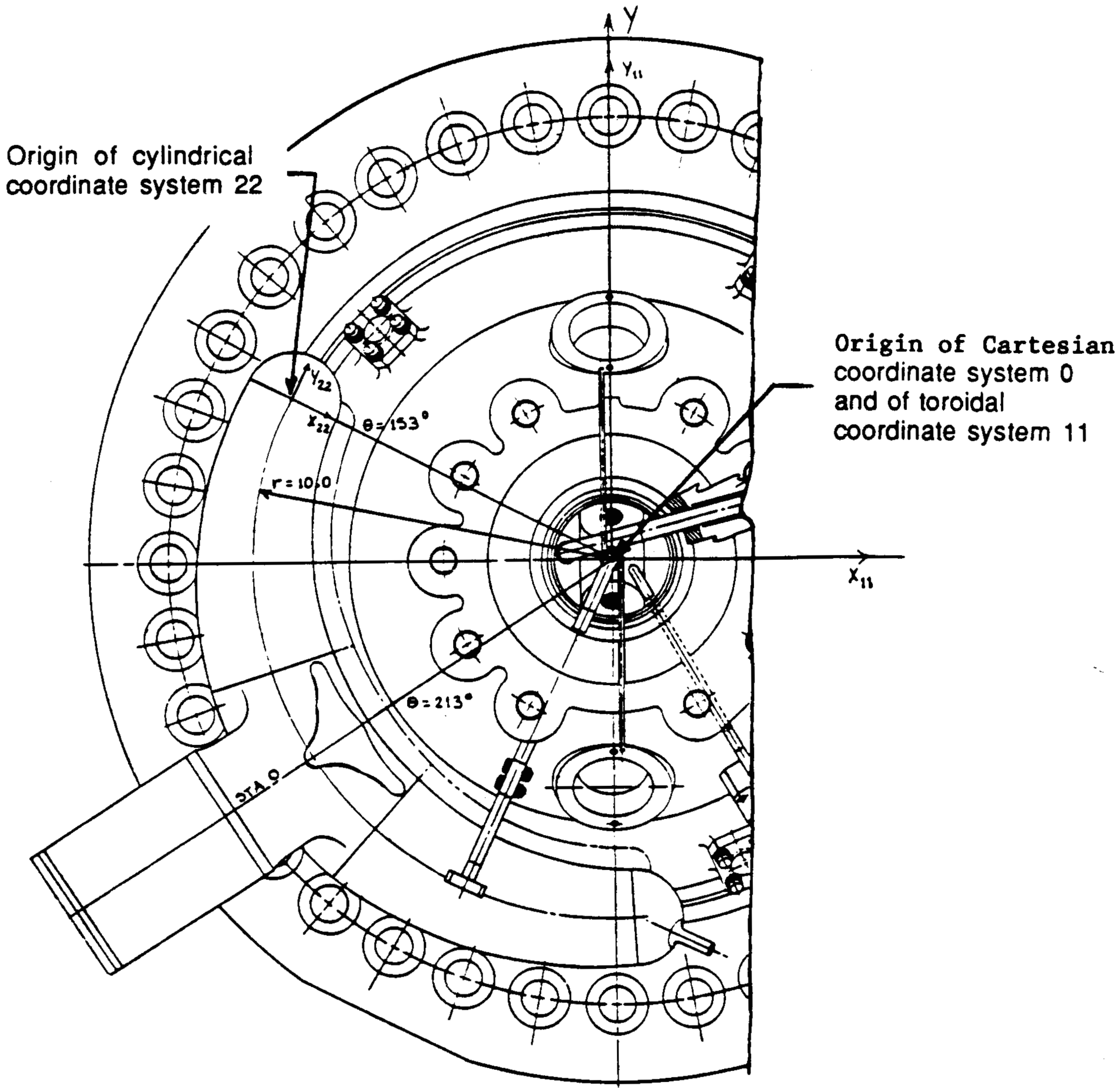

Figure 4 Location of Coordinate Systems 0, 11, 22

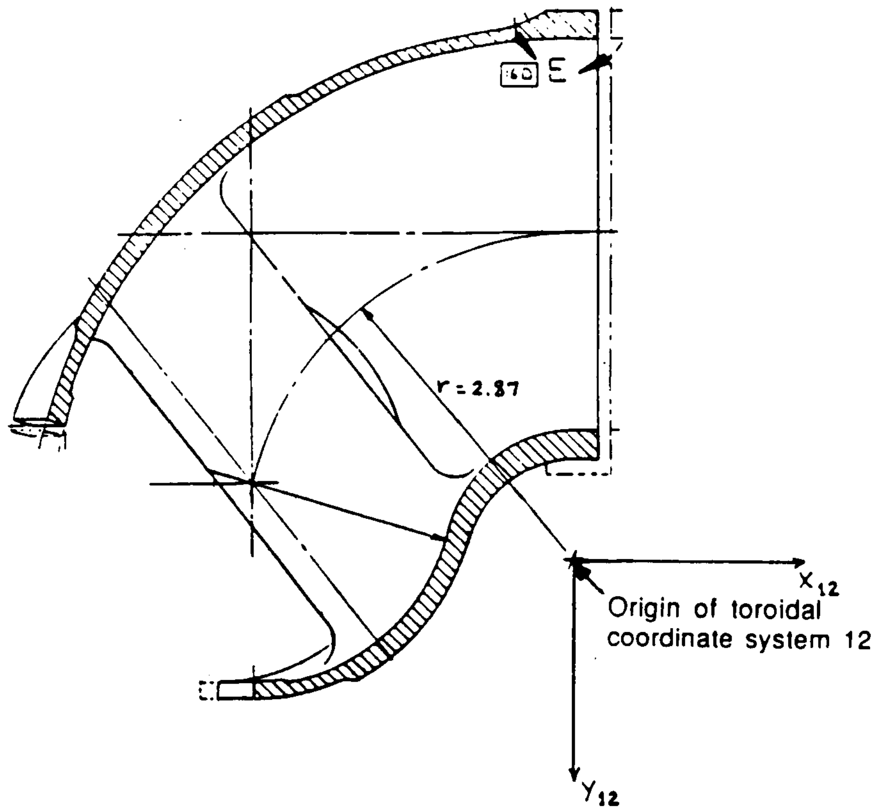

Figure 5 Location of Coordinate System 12

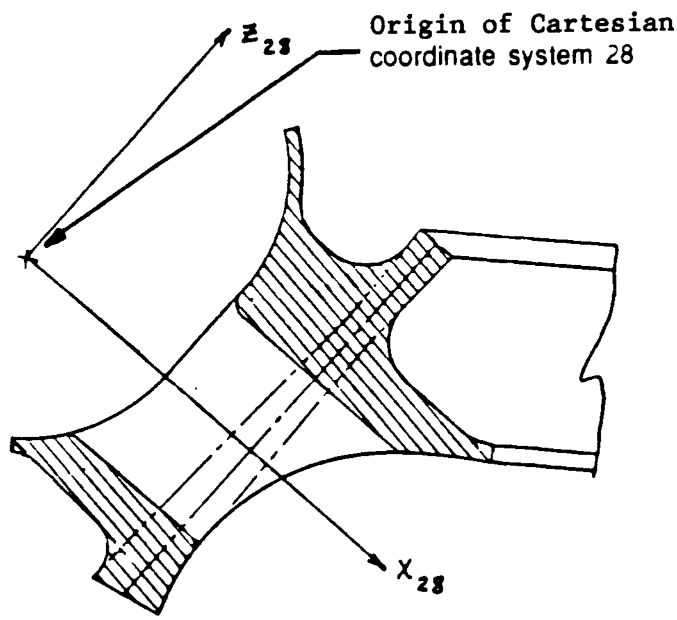

Figure 6 Location of Coordinate System 28

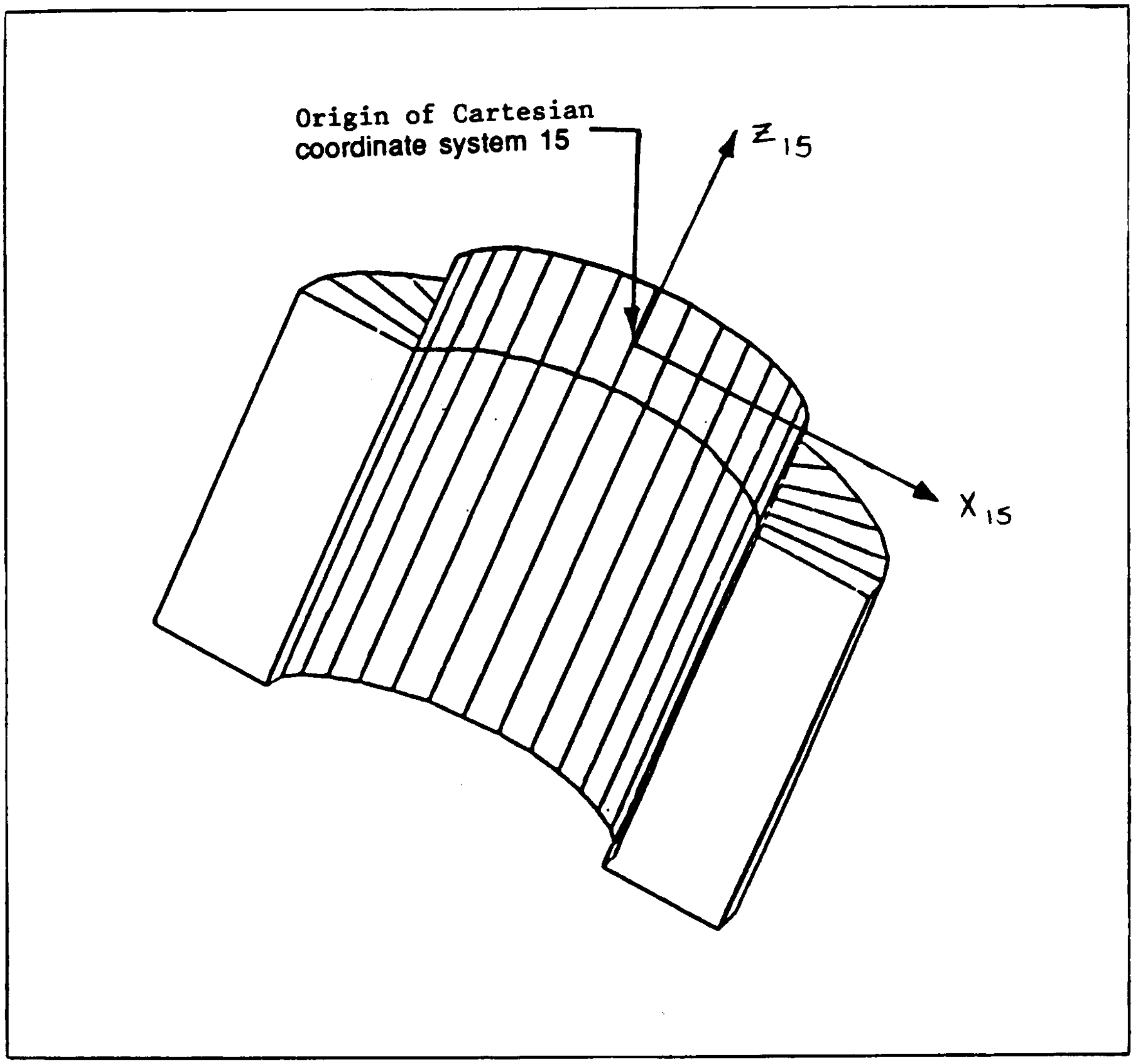

Figure 7 Location of Coordinate System 15

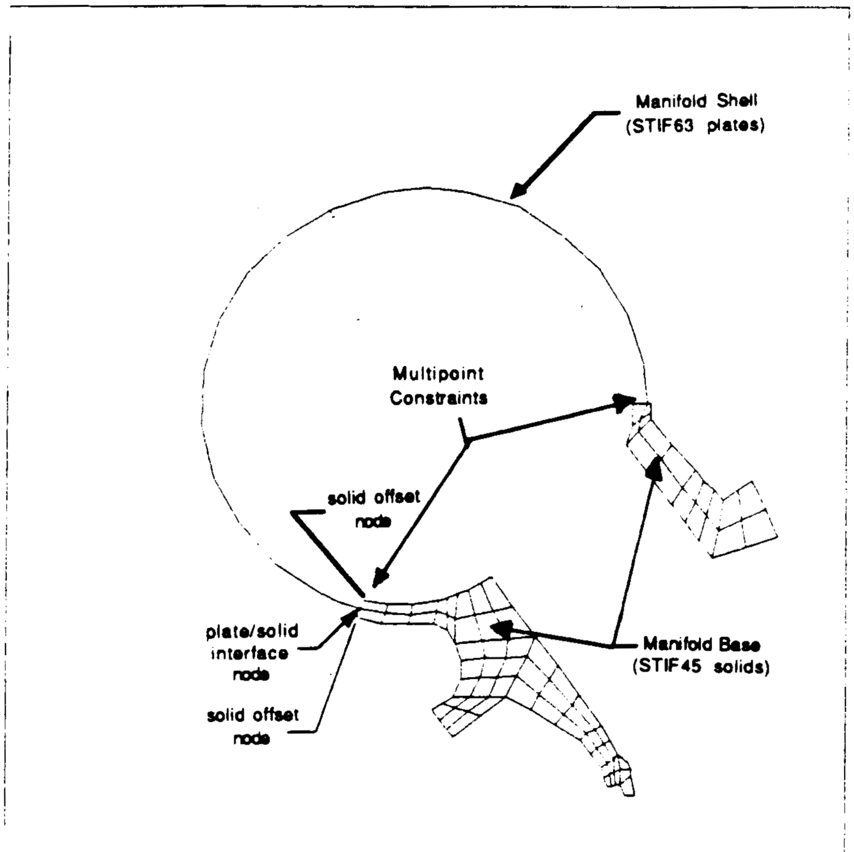

Figure 8 Typical Plate/Solid Interface

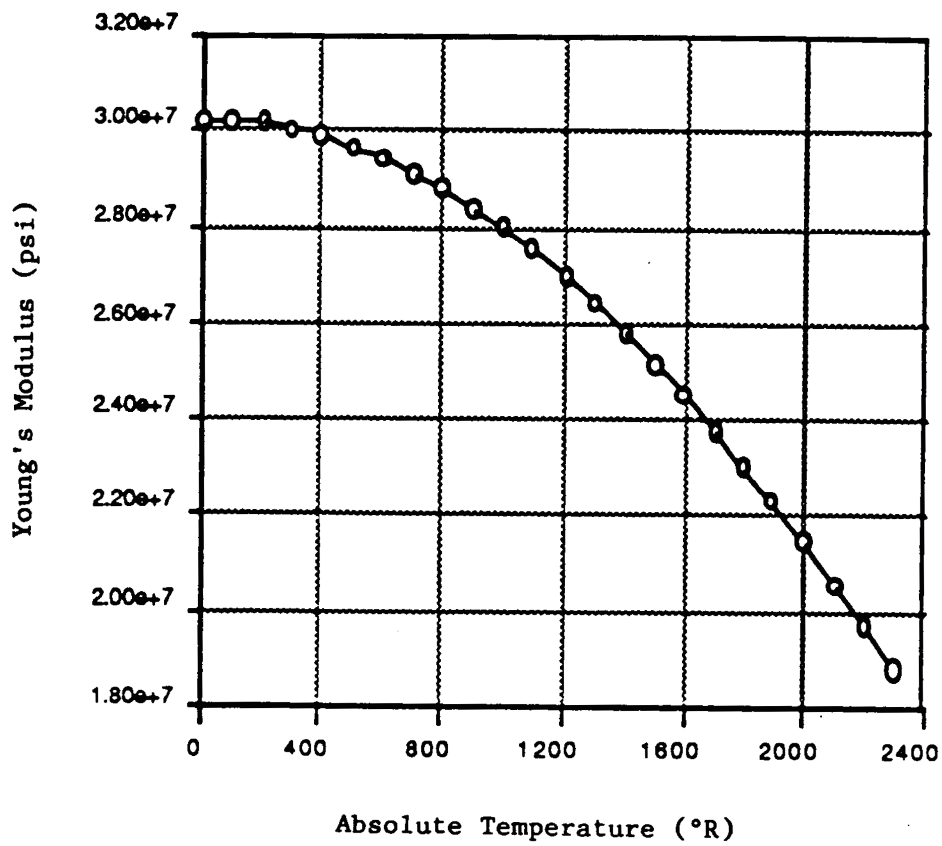

Figure 9 Inconel 817 Young's Modulus as a Function of Absolute Temperature

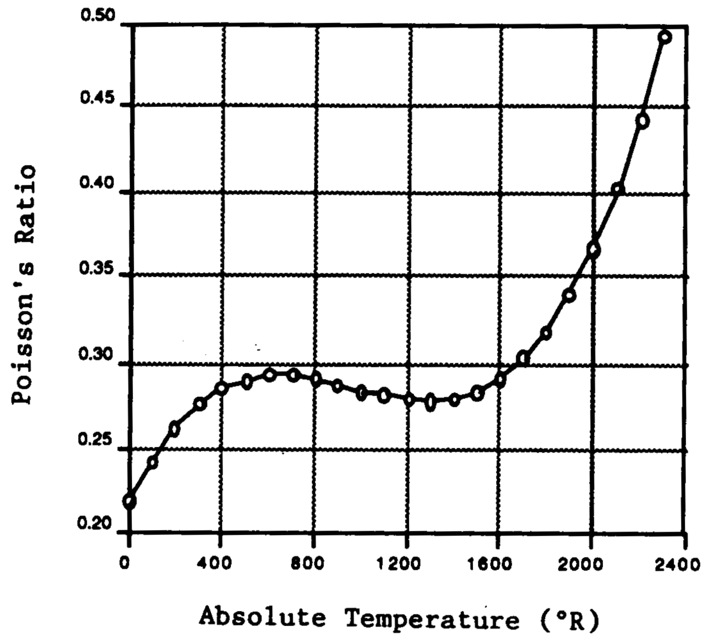

Figure 10 Inconel 718 Poisson's Ratio as a Function of Absolute Temperature

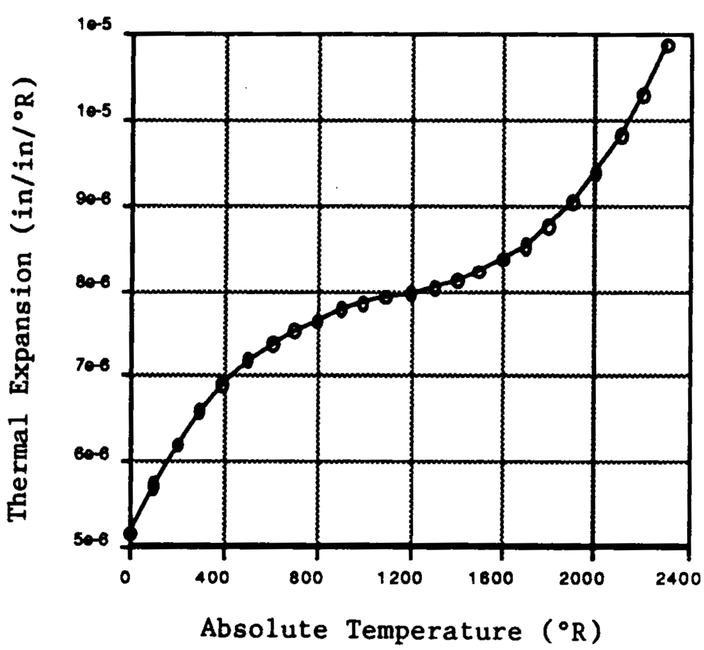

Figure 11 Inconel 718 Coefficient of Thermal Expansion as a Function of Absolute Temperature

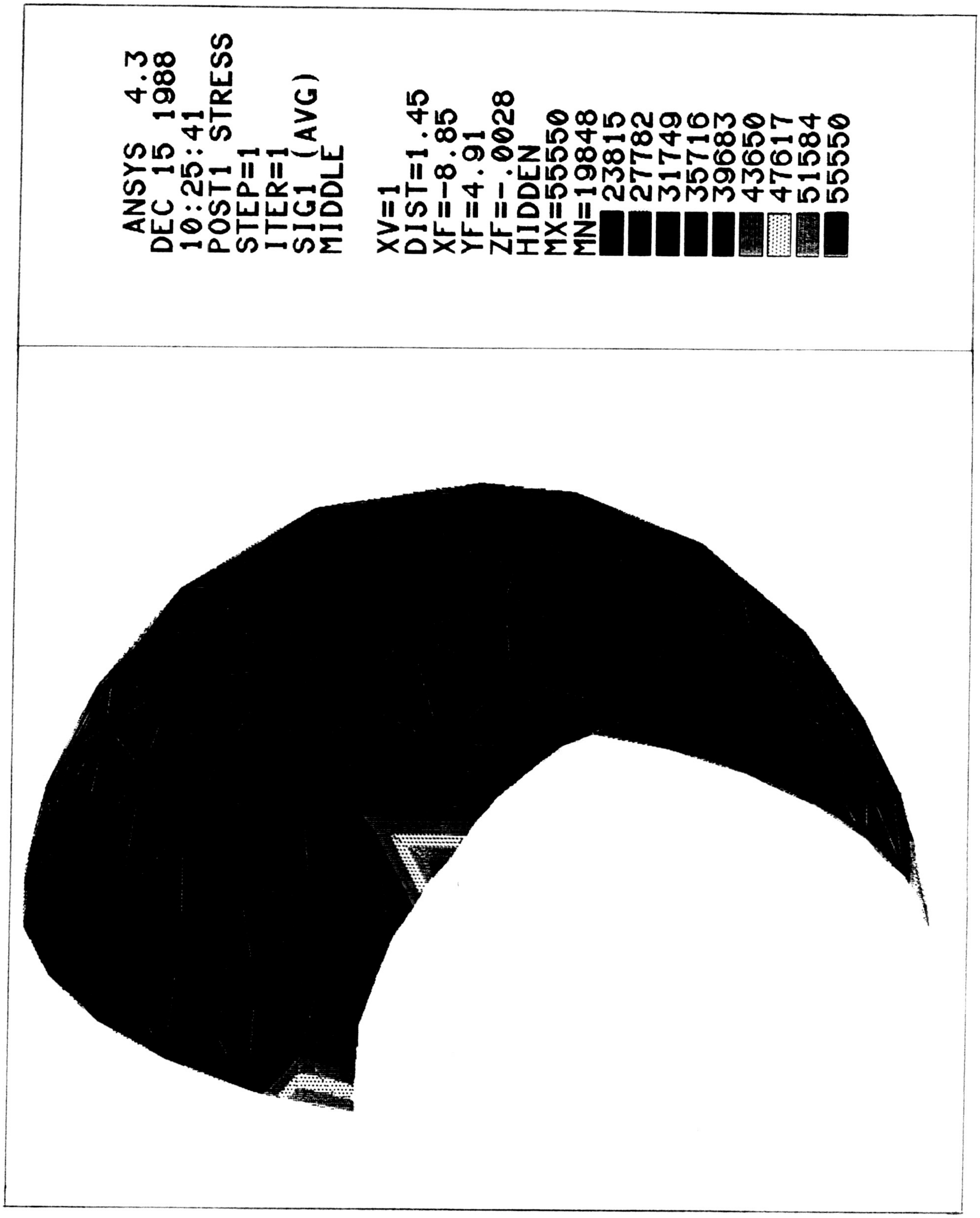

Figure 12 Maximum Principal Stress Contour Plot of Manifold Cap

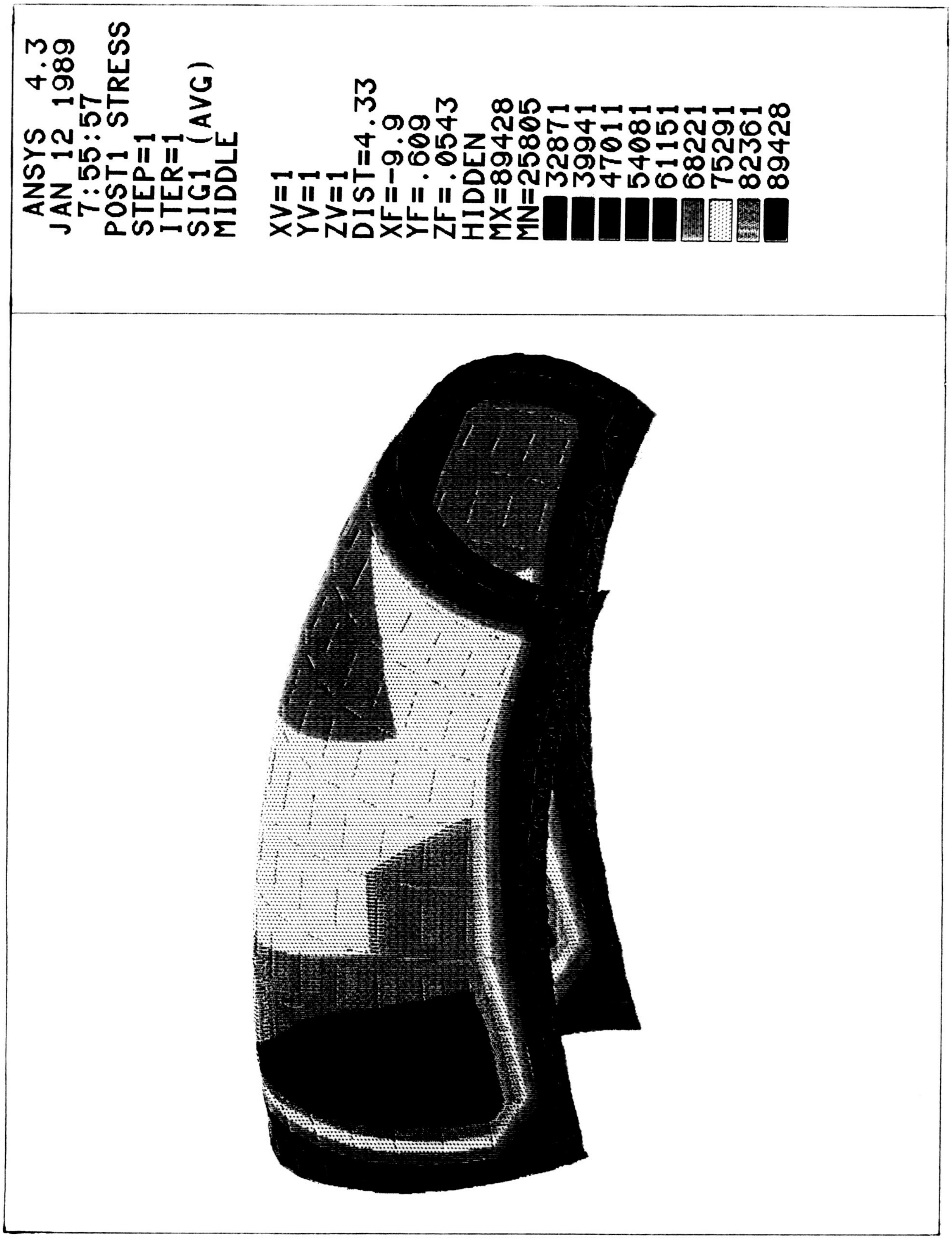

Figure 13 Maximum Principal Stress Contour Plot of Manifold Shell (View A)

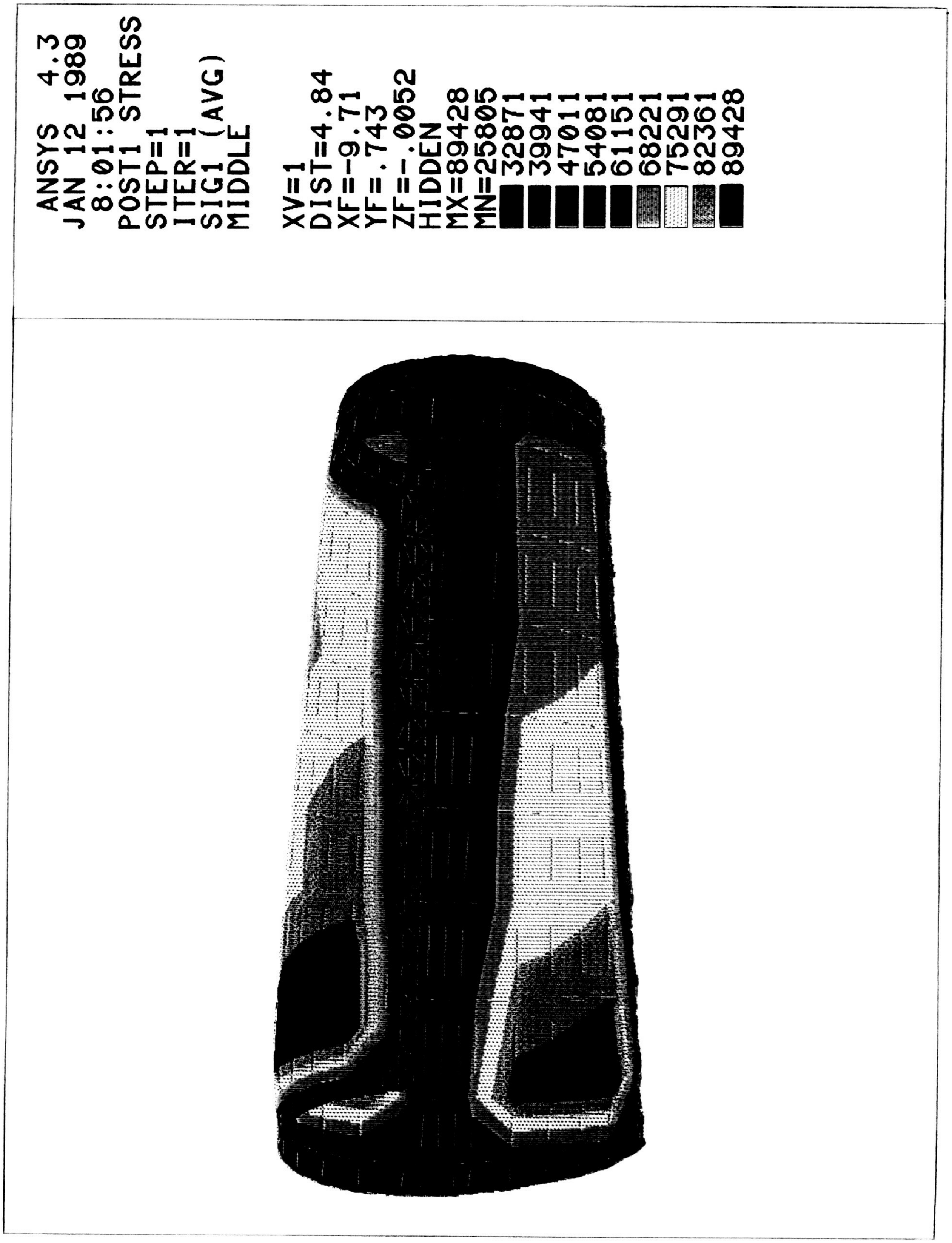

Figure 14 Maximum Principal Stress Contour Plot of Manifold Shell (View B)

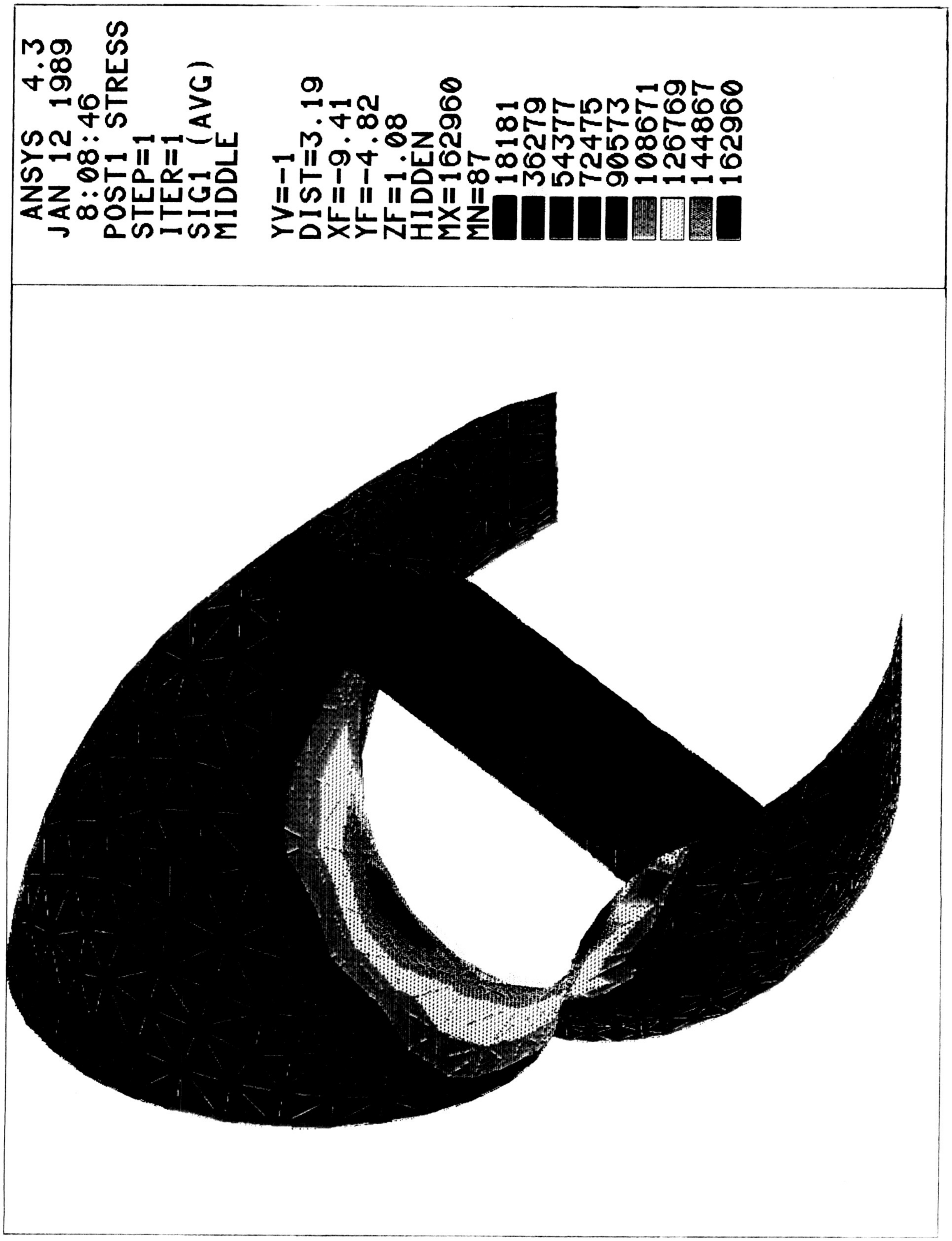

Figure 15 Maximum Principal Stress Contour Plot of Inlet Tee and Vane

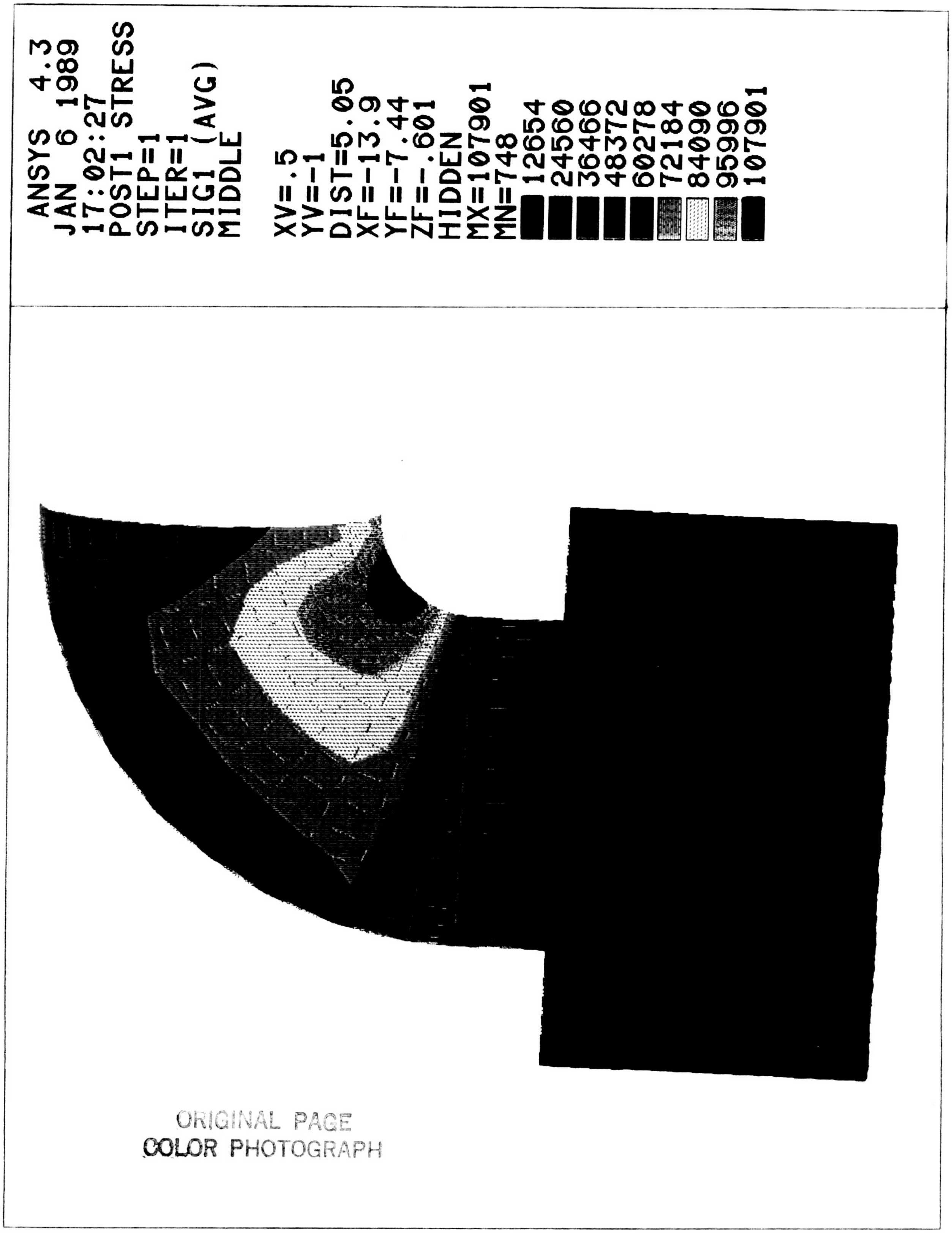

Figure 16 Maximum Principal Stress Contour Plot of Elbow and Flange

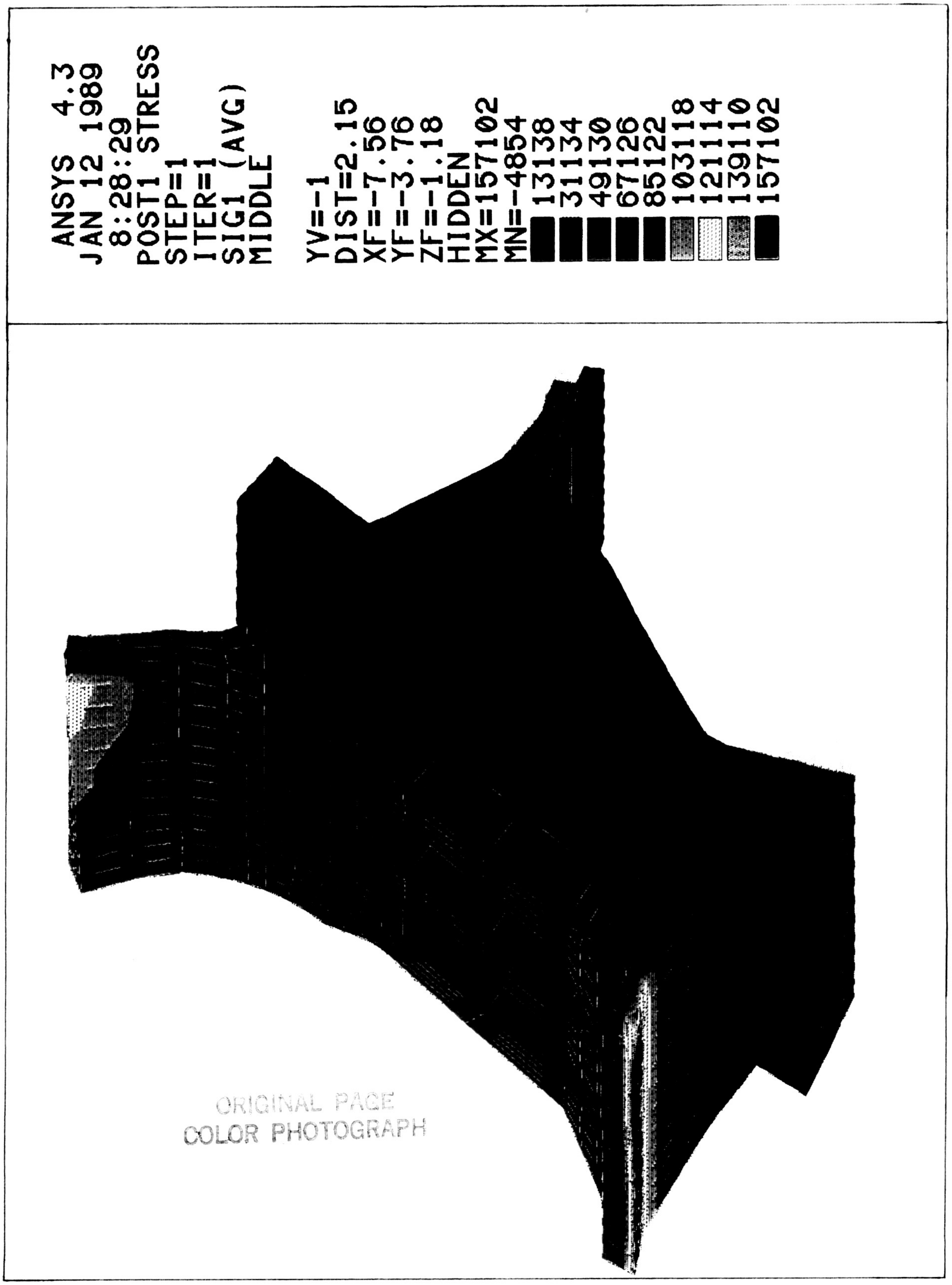

Figure 17 Maximum Principal Stress Contour Plot of Manifold Base

Appendix A
IBM AND CRAY RUNSTREAMS

APPENDIX A

IBM RUNSTREAM

```
//CCDJ202 JOB (6ED554590417),'REBECA',NOTIFY=CCDJ202,CLASS=A,
//  MSGCLASS=X
//DELETE EXEC PGM=IEFBR14
//F1   DD DISP=(MOD,DELETE),UNIT=SYSDA,
//     SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.LOX.FILE27
//F2   DD DISP=(MOD,DELETE),UNIT=SYSDA,
//     SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.LOX.FILE21
//F3   DD DISP=(MOD,DELETE),UNIT=SYSDA,
//     SPACE=(TRK,(1)),DSN=CCDJ202.ANSYS.LOX.FILE19
//*
//ANSYS43 EXEC ANSYS43,C=CATLG,
//          F19='CCDJ202.ANSYS.LOX.FILE19',
//          F21='CCDJ202.ANSYS.LOX.FILE21',
//          F27='CCDJ202.ANSYS.LOX.FILE27'
//GO.FILE18  DD UNIT=SYSDA,SPACE=(4642,(3000,500)),
//              DISP=(NEW,CATLG,DELETE),
//              DCB=(RECFM=FB,LRECL=80,BLKSIZE=4000)
//GO.FILE19 DD SPACE=(4642,(3000,500),RLSE),DISP=(NEW,CATLG)
//GO.FILE27  DD SPACE=(4652,(3000,500),RLSE),DISP=(NEW,CATLG)
//GO.FT05F001  DD DSN=CCDJ202.INJECT.DATA(LOX),
//     SPACE=(4096,(9000,1500),RLSE),DISP=SHR
```

CRAY RUNSTREAM

```
JOB,JN=CCDJ202,MFL=2500000,T=5000.
ACCOUNT,AC=6ED554590417,US=CCDJ202.
FETCH,DN=FT27,TEXT='DSN=CCDJ202.ANSYS.LOX.FILE27'.
ACCESS,DN=ANSYS,PDN=SOL43N,ID=ANSYS43,OWN=SYSTEM.
ACCESS,DN=AUTH43,ID=ANSYS43,OWN=SYSTEM. ACCESS AUTHORIZATION FILE
MODE,BT=DISABLE.
ANSYS.
SAVE,DN=FT14,PDN=LOXT14.
DISPOSE,DN=FT14,DC=ST,TEXT='DSN=CCDJ202.ANSYS.LOX.FILE14,'^
          'DISP=(,CATLG),'^
          'SPACE=(CYL,(20,2),RLSE),'^
          'DCB=(RECFM=FB,BLKSIZE=6320,LRECL=80)',WAIT.
/EOF
/CORE,2.0E6
/INPUT,27
FINISH
/AUX1
BCDCNV
FINISH
```